

## CLAIMS

I/We claim:

- [c1] 1. A computer-based method for locating a dipole source of a magnetic field, the dipole source being a marker implanted in or affixed to an organism, the method comprising:
- receiving a set of actual measurements, each actual measurement indicative of a component of the magnetic field at each of a plurality of sensors;
  - providing sets of reference measurements, each set of reference measurements being associated with a location such that an actual measurement from that location is expected to be a linear combination of that set;
  - selecting the location associated with the set of reference measurements that most closely matches the received set of actual measurements;
  - and
  - identifying a location associated with a set of calculated measurements that most closely matches the set of actual measurements wherein the set of calculated measurements is derived from the sets of reference measurements.
- [c2] 2. The method of claim 1 wherein the identifying of a location includes:
- calculating sets of calculated measurements corresponding to locations near the selected location based on the sets of reference measurements; and
  - selecting as the location of the source the location of the set of calculated measurements that most closely matches the set of actual measurements.

- [c3]            3.        The method of claim 1 wherein the identifying of the location includes searching for the location by iteratively determining how closely sets of calculated measurements match the set of actual measurements.
- [c4]            4.        The method of claim 1 wherein the marker is wireless.
- [c5]            5.        The method of claim 1 wherein the organism is a human.
- [c6]            6.        The method of claim 1 wherein sets of reference measurements are calculated.
- [c7]            7.        The method of claim 1 wherein the sets of reference measurements are experimentally derived.
- [c8]            8.        The method of claim 7 wherein the sets of reference measurements are experimentally derived by placing a dipole source of a magnetic field at various locations and receiving sets of actual measurements indicative of a component of the magnetic field from the sensors.
- [c9]            9.        The method of claim 7 wherein a set of reference measurements for a location comprises sets of actual measurements when the magnetic moment of the dipole source is oriented along an x axis, a y axis, and a z axis with one of the axes being approximately normal to a plane of the sensors.
- [c10]           10.       The method of claim 1 wherein the locations associated with the sets of reference measurements are at grid points within a bounding box that contains the source.
- [c11]           11.       The method of claim 1 wherein the closeness of a match between two sets of measurements is evaluated based on a least squares analysis.

- [c12] 12. The method of claim 1 wherein the closeness of a match between two sets of measurements is based on an evaluation of an objective function.
- [c13] 13. The method of claim 12 wherein the objective function is
- $$E_2 = \mathbf{s}^T \mathbf{H} (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \mathbf{s}.$$
- [c14] 14. The method of claim 1 wherein a set of calculated measurements is approximated based on sets of reference measurements for locations near the selected location.
- [c15] 15. The method of claim 14 wherein the approximation is a trilinear interpolation.
- [c16] 16. The method of claim 14 wherein the approximation is a combination of a trilinear and a second order difference interpolation.
- [c17] 17. The method of claim 14 wherein the marker is located within a bounding box divided into sub-boxes, the sub-boxes having corners that are grid points within the bounding box.
- [c18] 18. The method of claim 17 wherein the locations near the selected location correspond to corner grid points of the bounding sub-box that contains the source.
- [c19] 19. The method of claim 18 wherein the locations near the selected location further include grid points adjacent to the corner grid points.
- [c20] 20. The method of claim 1 wherein the identifying of a location includes identifying a point near a candidate point wherein a derivative of the objective function is near zero.

[c21] 21. The method of claim 1 wherein the identifying of a location includes calculating a spatial offset from a current location according to

$$\rho = -C^{-1} b.$$

[c22] 22. A computer-based method for locating a marker comprising a resonating magnetic circuit configured to exhibit a dipole magnetic moment and to generate a magnetic field in response to a wirelessly transmitted excitation signal, the marker being implanted in or affixed to an organism, the marker being located within a bounding box having grid points, the marker being located at a marker point within the bounding box, the method comprising:

receiving a set of actual measurements, each actual measurement indicative of a component of the magnetic field at each of a plurality of sensors, the sensors being substantially planar;

providing sets of reference measurements, each reference measurement being associated with one Cartesian component of the magnetic moment, each set of reference measurements being associated with a grid point such that when the marker is at that grid point the actual measurement is expected to be a linear combination of that set;

identifying a grid point that is close to the marker point by evaluating for various grid points an objective function that indicates the closeness of the set of actual measurements to the set of reference measurements at that grid point; and

identifying as the marker point a point associated with a set of calculated measurements that closely matches the set of actual measurements wherein the set of calculated measurements is derived from the sets of reference measurements and based on the objective function.

[c23] 23. The method of claim 22 wherein the identifying of the point as the marker point includes:

calculating sets of calculated measurements corresponding to points near the identified grid point based on the sets of reference measurements; and

selecting as the marker point the point of the set of calculated measurements that most closely matches the set of actual measurements.

[c24] 24. The method of claim 22 wherein the identifying of the point as the marker point includes identifying a point near a candidate point where a derivative of the objective function is near zero.

[c25] 25. The method of claim 23 wherein the objective function is represented by a Taylor series expansion.

[c26] 26. The method of claim 22 wherein the identifying of a point as the marker point includes calculating a spatial offset from a current point according to  $\mathbf{p} = -\mathbf{C}^{-1} \mathbf{b}$ .

[c27] 27. The method of claim 22 wherein the identifying of a point as a marker point includes searching for the point by iteratively determining how closely sets of calculated measurements match the set of actual measurements.

[c28] 28. The method of claim 22 wherein the marker is wireless.

[c29] 29. The method of claim 22 wherein the organism is a human.

[c30] 30. The method of claim 22 wherein sets of reference measurements are calculated.

[c31] 31. The method of claim 22 wherein the sets of reference measurements are experimentally derived.

[c32] 32. The method of claim 31 wherein the sets of reference measurements are experimentally derived by placing a dipole source of a magnetic field at various grid points and receiving sets of actual measurements indicative of a component of the magnetic field from the sensors.

[c33] 33. The method of claim 31 wherein a set of reference measurements for a grid point comprises sets of actual measurements when the magnetic moment of the dipole source is oriented along an x axis, a y axis, and a z axis with one of the axes being approximately normal to a plane of the sensors.

[c34] 34. The method of claim 22 wherein the objective function is based on a least squares analysis.

[c35] 35. The method of claim 22 wherein the objective function is

$$E_2 = \mathbf{s}^T \mathbf{H} (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \mathbf{s}.$$

[c36] 36. The method of claim 22 wherein a set of calculated measurements is approximated based on sets of reference measurements for grid points near the identified grid point.

[c37] 37. The method of claim 36 wherein the approximation is a trilinear interpolation.

[c38] 38. The method of claim 36 wherein the approximation is a combination of a trilinear and a second order difference interpolation.

[c39] 39. The method of claim 22 wherein the marker is located within a bounding box divided into sub-boxes, the sub-boxes having corners that are grid points within the bounding box.

[c40]           40.    The method of claim 39 wherein the grid points near the identified grid point correspond to corner grid points of the bounding sub-box that contains the marker.

[c41]           41.    The method of claim 40 wherein the grid points near the identified grid point further include grid points adjacent to the corner grid points.

[c42]           42.    A system for locating a dipole source of a magnetic field, the dipole source being a marker implanted in or affixed to an object, the method comprising:  
                  means for receiving a set of actual measurements, each actual measurement indicative of a component of the magnetic field at each of a plurality of sensors;  
                  means for selecting the location associated with a set of reference measurements that most closely matches the received set of actual measurements, each set of reference measurements being associated with a location such that an actual measurement from that location is expected to be a linear combination of that set; and  
                  means for identifying a location associated with a set of interpolated reference measurements that most closely matches the set of actual measurements.

[c43]           43.    The system of claim 42 wherein the means for identifying a location include means for calculating sets of interpolated reference measurements corresponding to locations near the selected location from the sets of reference measurements.

[c44]           44.    The system of claim 42 wherein the means for identifying the location include means for searching for the location by iteratively determining how closely sets of interpolated reference measurements match the set of actual measurements.

[c45] 45. The system of claim 42 including means for calculating sets of reference measurements.

[c46] 46. The system of claim 42 including means for experimentally deriving the sets of reference measurements.

[c47] 47. The system of claim 42 wherein the locations associated with the sets of reference measurements are at grid points within a bounding box that contains the source.

[c48] 48. The system of claim 42 wherein the means for identifying the location include means for performing a trilinear interpolation.

[c49] 49. The system of claim 42 wherein the means for identifying the location include means for performing a trilinear interpolation and a second order difference interpolation.

[c50] 50. A method for locating a dipole source of a magnetic field, the dipole source being a marker implanted in or affixed to an organism, the method comprising:

selecting a location associated with a set of reference measurements that most closely matches a set of actual measurements, an actual measurement being indicative of the magnetic field, a set of reference measurements being indicative of actual measurements expected when the dipole source is at the associated location; and identifying a location associated with a set of interpolated reference measurements that most closely matches the set of actual measurements wherein the set of interpolated reference measurements is derived from sets of reference measurements.

- [c51] 51. The method of claim 50 wherein the identifying of the location includes searching for the location by iteratively determining how closely sets of interpolated reference measurements match the set of actual measurements.
- [c52] 52. The method of claim 50 wherein the marker is wireless.
- [c53] 53. The method of claim 50 wherein sets of reference measurements are calculated.
- [c54] 54. The method of claim 50 wherein the sets of reference measurements are experimentally derived.
- [c55] 55. The method of claim 50 wherein the locations associated with the sets of reference measurements are at grid points within a bounding box that contains the source.
- [c56] 56. The method of claim 50 wherein the closeness of a match between two sets of measurements is based on an evaluation of an objective function.
- [c57] 57. The method of claim 56 wherein the objective function is
$$E_2 = \mathbf{s}^T \mathbf{H} \left( \mathbf{H}^T \mathbf{H} \right)^{-1} \mathbf{H}^T \mathbf{s}.$$
- [c58] 58. The method of claim 50 wherein the approximation is a trilinear interpolation.
- [c59] 59. The method of claim 50 wherein the approximation is a combination of a trilinear and a second order difference interpolation.

[c60] 60. The method of claim 50 wherein the identifying of a location includes identifying a location near a candidate location wherein a derivative of an objective function is near zero.

[c61] 61. The method of claim 50 wherein the identifying of a location includes calculating a spatial offset from a current location according to

$$\rho = -C^{-1} \mathbf{b}.$$

[c62] 62. A computer-based method for locating a dipole source of a magnetic field, subject to interference from other sources, the dipole source being a marker implanted in or affixed to an organism, the method comprising:

receiving a set of actual measurements, each actual measurement indicative of a component of the magnetic field and a component of the interference at each of a plurality of sensors;

providing sets of reference measurements, each set of reference measurements being associated with a location such that an actual measurement from that location in the absence of interference is expected to be a linear combination of that set;

providing a set of augmented measurements, such that interference at the sensors is expected to be a linear combination of that set; and

selecting the location associated with the set of reference measurements as augmented by the set of augmented measurements that most closely matches the received set of actual measurements.

[c63] 63. The method of claim 62 including weighting the reference measurements to account for reliability of sensors in a sensor array.

[c64] 64. The method of claim 63 wherein the weighting is provided by multiplying the reference measurements by a whitening matrix.

[c65]            65.    The method of claim 62 including weighting the actual measurements to account for reliability of sensors in a sensor array.

[c66]            66.    The method of claim 65 wherein the weighting is provided by multiplying the actual measurements by a whitening matrix.

[c67]            67.    The method of claim 62 wherein the set of augmented measurements is an augmentation matrix.

[c68]            68.    A computer-based method for locating a dipole source of a magnetic field, subject to interference from other sources, the dipole source being a marker implanted in or affixed to an organism, the method comprising:

                 receiving a set of actual measurements, each actual measurement indicative of a component of the magnetic field wherein the reliability of the actual measurements varies;

                 providing sets of reference measurements, each set of reference measurements being associated with a location such that an actual measurement from that location is expected to be a linear combination of that set;

                 providing a set of reliability weights that reflects the reliability of the actual measurements; and

                 selecting the location associated with the set of reference measurements that most closely matches the received set of actual measurements factoring in the reliability weights.

[c69]            69.    The method of claim 68 wherein the set of reliability weights reflects the reliability of sensors in a sensor array.

[c70]            70.    The method of claim 68 wherein the set of reliability weights is applied to the actual measurements.

[c71]            71.    The method of claim 68 wherein the set of reliability weights is applied to the reference measurements.